Research in Astron. Astrophys. **2010** Vol. **10** No. **10**, 1061–1070
http://www.raa-journal.org *http://www.iop.org/journals/raa*

Research in Astronomy and Astrophysics

Seeing measurements for the Guoshoujing Telescope (LAMOST) site with DIMM *

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Received 2010 April 1; accepted 2010 May 19

Abstract We present seeing measurements of the Guoshoujing Telescope (formerly named the Large Sky Area Multi-Object Fiber Spectroscopic Telescope- LAMOST) site at Xinglong station during the period from 2007 March 12 to April 25. The measurements were carried out with the Differential Image Motion Monitor (DIMM), and a total of 9259 data sets was obtained. The median seeing was measured to be 1.1″, with 25% being better than 0.8″and 75% better than 1.5″. The experiment shows that the DIMM exposure time has significant effects on the results of seeing measurements. An SBIG Polaris seeing monitor, which had been planned to be installed on the LAMOST site for long-term monitoring, was also employed during the DIMM observations. The results show that the SBIG seeing monitor is easily affected by gusty wind, resulting in larger seeing values. Considering the previous seeing measurements at Xinglong station over the last 15 yr, we conclude that an acceptable seeing condition at Xinglong station is around 1″–2″.

Key words: techniques: atmospheric turbulence seeing — instrumentation: DIMM — site testing: LAMOST

1 INTRODUCTION

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST), now named the Guoshoujing Telescope, is a quasi-meridian reflecting Schmidt telescope constructed with its optical axis fixed in the meridian plane. LAMOST is an innovative telescope with a 4 m aperture, a field of view of 5 degrees, and 4000 fibers installed on a 1.75 m focal plane (Cui 2009). LAMOST is located at Xinglong station, 950 m above sea level and 170 km northwest of Beijing, and is designed to be the major optical/IR site for the Chinese astronomical community. Understanding the seeing conditions is vital to astronomical observations, which inevitably have an important impact on the performance of the optical spectrometers and the scientific goals of LAMOST. To set an upper limit on the slit width of the high resolution spectrograph for LAMOST, the parameters of atmospheric

* Supported by the National Natural Science Foundation of China.

turbulence nearby the LAMOST dome are required. The seeing measurements were carried out on the western platform outside the LAMOST dome from 2007 March 12 to April 25.

Since the 1990s, several seeing measurement campaigns have been run at Xinglong station. Song et al. (1998) reported the turbulence measurements at Xinglong station using DIMM (Differential Image Motion Monitor), FWHM (full width at half maximum), a microthermal sensor and acoustic radar. They obtained atmospheric refractive index structure constant profiles and the coherence length of the entire atmosphere in the 2.16 m telescope dome, so the seeing values should cover the dome seeing. In addition, their campaign covers only four nights, and can be taken as short-term characteristics of the local optical turbulence (Song et al. 1998; Wu et al. 1996). Liu et al. (2003) analyzed the Polaris images taken by the Schmidt telescope at the Xinglong station in 1995–2001, which is part of the BATC sky survey project. Using the mean FWHM of unsaturated bright stars in the images, they provided an objective estimation for seeing conditions at Xinglong station, ranging over $2''$–$5''$, and they found that the mean FWHM is better in summer than that of winter. For the longtime data sets, Liu et al. (2003)'s study can be an important reference for understanding the seasonal features of the seeing conditions at Xinglong station, although the FWHM method usually brings in larger seeing values, due to some non-turbulence factors and dome seeing.

It has been well known that seeing characterizes the entire atmospheric turbulence including the near-surface layer, the boundary layer and the free atmosphere. The near-surface turbulence is the main factor inducing seeing; it is very sensitive to local topography, vegetation and the layout of surrounding buildings (Coulman 1985). The LAMOST telescope is located at a height of 28 meters above the ground, where turbulent conditions should not be strongly affected by the ground vegetation and buildings. In this sense, our seeing measurements provide not only the parameters of local turbulence for the high resolution spectrometer design, but also a practical seeing evaluation for Xinglong station. This paper presents our seeing measurements from 2007 March 12 to April 25.

2 OBSERVATIONS

A set of DIMMs was employed for the observations. The DIMM technique was first introduced by Sarazin & Roddier (1990), by which the seeing is measured via the differential positions of two sub-aperture images of a star. This technique has the advantage of being insensitive to telescope and ground vibration. The instrument has been widely used in many astronomical observatories and site testing for future large telescopes (e.g., Thirty Meter Telescope, European Extremely Large Telescope, and Chinese Future Giant Telescope). Our DIMM configuration is the following: (1) a small telescope equipped with two sub-pupils; (2) an optical wedge installed on one sub-pupil, to adjust an appropriate separation between the two star images on the focal plane; (3) a CCD camera, attached to the telescope focal plane for fast sampling of the star images; (4) two sets of control computers. One accumulates star images from the CCD camera and processes seeing values, while doing real time tracking through a guide CCD. The other computer was placed in the control room of the LAMOST dome, and, through the internet, it can remotely control the outdoor computer. Table 1 shows the specifications of the DIMM.

Table 1 DIMM Specifications

Device	Parameters
Telescope	Meade LX200GPS
Diameter	20 cm
Sub-aperture	diameter 5 cm
Sub-aperture separate	15 cm
Detector	Sony CCD ICX429ALL
Pixel scale	$0.58''$

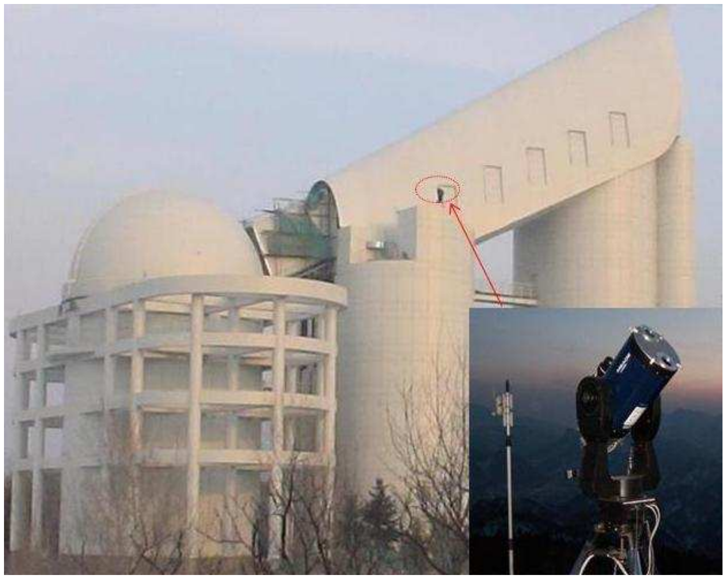

Fig. 1 Layout of DIMM observations.

Figure 1 shows the layout of the DIMM observations. The DIMM telescope is set up on the west platform of the LAMOST dome, at the same height as the primary mirror of LAMOST. The CCD exposure time was usually set to be 10 ms for seeing measurements, and one seeing value was calculated based on a set of 100 images. The final results have been corrected with the real time zenith angle. In order to perform further data analysis, an automatic weather station (LA CROSSE TECHNOLOGY, WS-2010 USA) was also set up nearby the DIMM telescope, with sensors of air temperature and pressure, relative humidity, and wind speed and direction.

Because the SBIG Polaris seeing monitor was designed to be an automatic instrument installed at the LAMOST site for long-term monitoring, calibration was also made for the Polaris Seeing monitor with our DIMM observations. The Polaris Seeing monitor was developed using the ST-402ME

Table 2 DIMM Seeing Observing Log and Nightly Results

Date	Period	Num. data set	Median seeing (arcsec)
Mar–12	21:38–04:20	588	1.47
Mar–13	19:39–03:58	871	1.10
Mar–14	22:15–05:44	989	0.72
Mar–15	20:52–23:56	397	1.22
Mar–16	20:05–06:04	1337	0.71
Mar–17	19:03–06:00	1170	1.11
Mar–21	20:27–22:05	123	1.14
Mar–25	19:24–05:46	1160	1.75
Mar–28	19:53–22:34	219	1.67
Mar–29	19:33–00:48	448	1.33
Apr–24	20:15–04:59	1154	0.91
Apr–25	21:16–05:04	803	1.39

The observing targets for DIMM seeing monitoring are β Gem (1.14 mag), α Leo (1.35 mag), α Uma (1.79 mag), α Boo (–0.04 mag), α Lyr (0.03 mag), ϵ Uma (1.77 mag), α Aur (0.08 mag).

CCD with TDI readout mode, and the exposure time was set to 5 ms. The optical configuration was a set of F/5.3 lenses, providing a field of view of $2.7^\circ \times 1.6^\circ$. The Polaris seeing monitor was fixed on an equatorial mount (Meade LXD75) near the DIMM telescope. The seeing values were calculated automatically according to the Polaris trail (Harlan & Walker 1965).

Table 2 shows the DIMM Seeing observing log at Xinglong station from 2007 March 12 to April 25, and presents the number of effective data sets and the median seeing for the 12 nights. In the last two nights of this run, we carried out seeing measurements simultaneously using the Polaris seeing monitor and the DIMM. The automatic weather station had been employed from March 14 to April 25.

3 RESULTS

A total of 12 nights of data sets were obtained for the seeing measurements at the LAMOST site. Depending on the weather conditions, we could take at best 1337 data sets during one night, and 123 data sets in the worst case. A total of 9259 valid data sets is used in the analysis, and the median seeing in this run is measured to be $1.1''$.

Figure 2 shows an example of the DIMM seeing measurements on 2007 March 16. The seeing condition of this night is the best in the whole run, with 1337 data sets in whole night. The very good seeing level indicates a very stable weather condition during the night. The overall trend of the seeing is decreasing, with about $1.0''$ before midnight, $0.7''$ at midnight and $0.6''$ after midnight. It can be easily noticed there was relatively strong turbulence activity around 22:30, and only light turbulence happened around 20:30, 1:30, and 3:40–4:20. The median seeing value overnight is $0.7''$. The average wind speed at this night was 2.8 m s^{-1}.

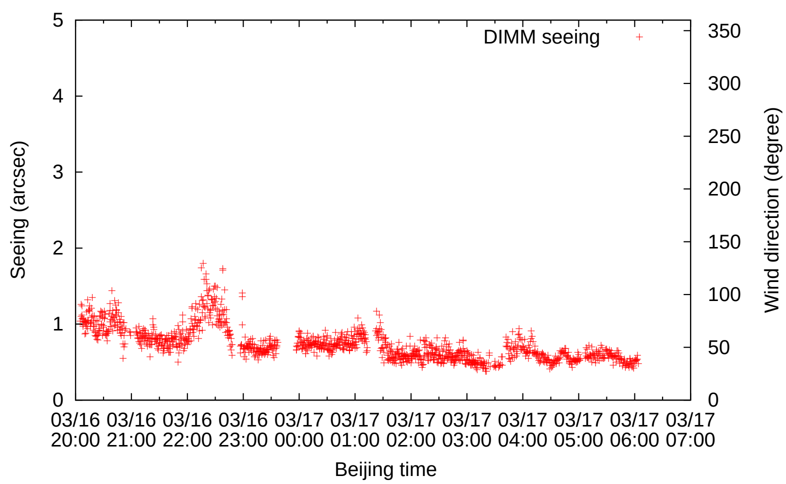

Fig. 2 An example of a good seeing night on 2007 March 16.

Figure 3 shows an example, on 2007 March 25, of a bad seeing night in the observations. In total, 1160 data sets were obtained, indicating that it was still a fine night; the local wind was not so strong and the average wind speed overnight was only 2.4 m s^{-1}. However, the median seeing was measured to be $1.8''$, a rather poor seeing condition. The overall trend of the seeing values in the night is clearly different from that on March 16, and shows a whole trend of increasing seeing before midnight and large fluctuations in seeing after midnight. There was also a feature in the bad seeing

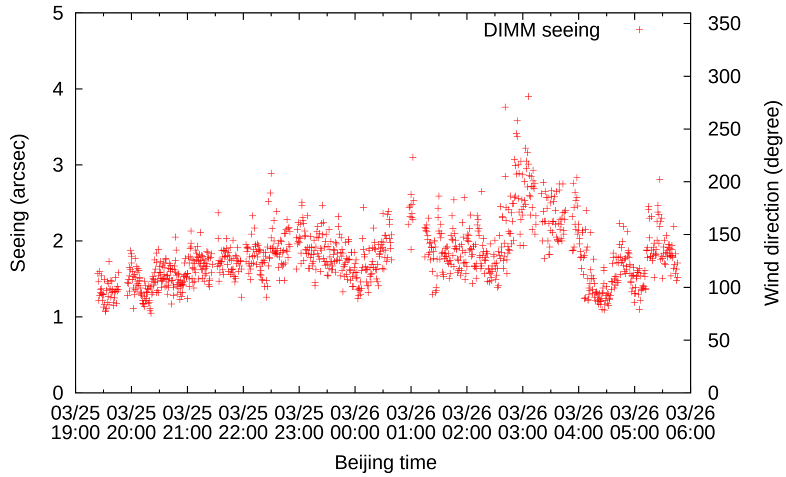

Fig. 3 An example of a bad seeing night on March 25.

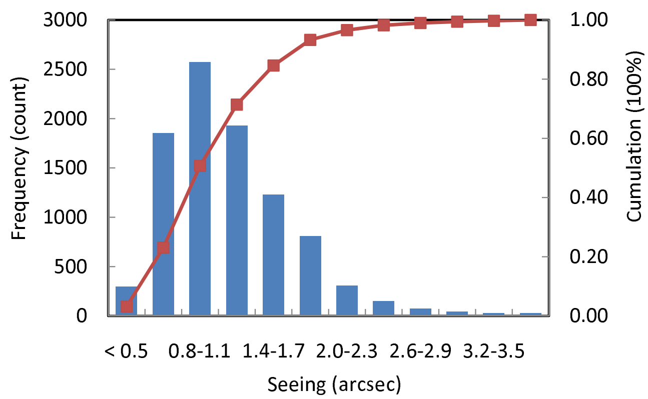

Fig. 4 Statistical distribution of the seeing measurements from 2007 March to April.

night, where the seeing values fluctuated with high frequency and large standard deviation. It could be supposed that high altitude turbulence had progressively developed before midnight, and became much more vigorous in the latter half of the night. Some turbulence activities can be indicated by temporal maxima of seeing values at 23: 00, 1: 00 and 4: 50; the turbulence activity was the strongest during the period from 2: 30 to 4: 30, when the seeing value was 2″–3″.

Figure 4 presents the statistical distribution of seeing from 2007 March to April. The probability peak of the seeing measurements is around 1.0″, the median seeing is measured to be 1.1″and the mean seeing is 1.2″. A fraction of 25% of the total data sets shows seeing better than 0.8″, and 75% is better than 1.5″.

The Polaris seeing monitor recorded 396 data sets of seeing during the night of April 24, and most of the seeing values are distributed in the range of 1″–5″, with a median seeing of 2.1″. Also, 465 seeing data sets were recorded in the night of April 25, and the seeing spread was from 1.3″ to 5″, with a median seeing of 2.2″.

4 DISCUSSION

4.1 Effect of Exposure Time on Seeing Measurements

According to the Kolmogorov theory, turbulent atmospheric cells form in various sizes, and depending on the size of the cells and the wind speed, the turbulence phase fluctuation can be induced at various frequencies. There is a highly debatable question about the DIMM technique, whether the whole frequency power spectrum can be measured with the DIMM seeing. It is supposed that the star image motion is "frozen," i.e. the exposure time of the star images has to be too short to allow the turbulent cell to move across the two sub-apertures. If the exposure time is not so short, then the seeing caused by the high-frequency turbulence would not be measured, because the high-frequency contribution to the image motion is smeared out.

It is usually thought that most seeing might be caused by phase fluctuations with frequencies less than 100 Hz (Zhang & Chi 2001; Tokovinin 2002). Therefore, an exposure time of 10 ms should be enough to achieve viable seeing measurements by using the DIMM method. In order to check the assumption, we have performed experiments by using three different exposure times: 5 ms, 10 ms, and 20 ms. On average, four groups of data sets with different exposures were obtained every night, and we obtained a total of 49 groups in this run. The data reduction showed that seeing values became smaller with longer exposure times; on average, the median seeing with a 10 ms exposure is $0.3''$ lower than that with a 5 ms one, and the median seeing with a 20 ms exposure of $0.2''$ is lower than that of a 10 ms one.

Figure 5 shows the linear regression analysis for the sample of 49 data sets with different exposure times. There is clearly a strong correlation among different exposure times; the correlation coefficient is measured to be 0.93 between the 5 ms and 10 ms seeing values, and 0.94 between the 10 ms and 20 ms ones. Therefore, the results of regression analysis could be directly employed to calibrate the seeing measurements with different exposure times. Our experimental results have shown a good agreement with those investigated by Sarazin & Roddier (1990), Vernin (1995) and Tokovinin (2002).

Based on the experiment, we may conclude that DIMM seeing measurements are sensitive to the exposure time. Under different weather conditions, a 10 ms exposure time may not be sufficient to 'freeze' the turbulent atmosphere, and the high-frequency turbulent fluctuations often cause a notable bias in seeing evaluations. In our measurements, the 5 ms seeing values are 1.14 times higher than those of the 10 ms ones, and the 10 ms ones are 1.18 times higher than those of the 20 ms cases.

This conclusion can be very important for accurately understanding the seeing evaluations and comparisons among various observatories and candidate sites. The DIMM exposure time must be taken into account for seeing evaluations. Just as the corrections in seeing measurements for zenith angle, observing band, and the height above ground have been required, we should also make a criterion for the exposure time. It may be acceptable for publishing standard seeing values to make the exposure time correction accurate to 1 ms.

4.2 Comparison of DIMM with Polaris Seeing

In view of the portable Polaris seeing monitor becoming popular in recent years in astronomical observatories, it is necessary to further discuss and confirm the results of the Polaris seeing monitor. Figure 6 shows examples of the simultaneous observations with both the DIMM and Polaris seeing monitor. The DIMM seeing has already been calibrated to be 5 ms, the same exposure time as the Polaris seeing. It could be noticed that the unpredictable seeing ups and downs are basically the same for the two types of instruments, but the DIMM seeing values are significantly lower than the Polaris seeing. The median DIMM seeing is $1.0''$, but the median Polaris seeing is $2.1''$.

The large differences of the Polaris seeing from DIMM seeing may be due to two factors. (1) The target stars of DIMM are near the zenith, while the Polaris seeing monitor continuously peers

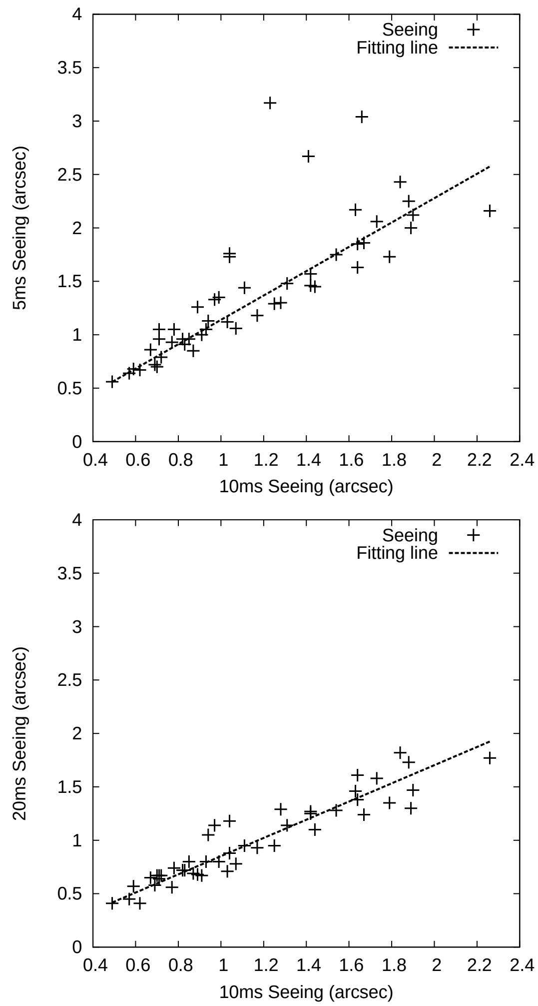

Fig. 5 Effect of exposure time on seeing measurements. The two plots display that the seeing values become smaller with longer exposure times, and follow linear correlations. In the 5–10 ms seeing plot, a 3σ clipping was employed on the dataset before the regression line fitting.

at the Polaris field. The zenith angle of Polaris is about 50 degrees at Xinglong observatory, and the Polaris light passes through a long slanted path with a much larger airmass (1.6), so that the Polaris seeing may be more easily affected by the boundary and tropospheric turbulence layers. The zenith angle correction causes the large errors. (2) The DIMM seeing employs a differential image motion method that can completely rule out the impact of the telescope track and wind load, while the Polaris seeing monitor simply uses a star trail method which can be easily affected by the equipment jitter caused by wind load, although the instrument setup has no tracking. In fact, based on our long experience in operating the DIMM, even if the equipment is installed on a fixed roof, human outdoor and indoor activities would lead to an overall swing in the star images. In Section 4.3, we discuss evidence of the Polaris seeing monitor impacted by wind.

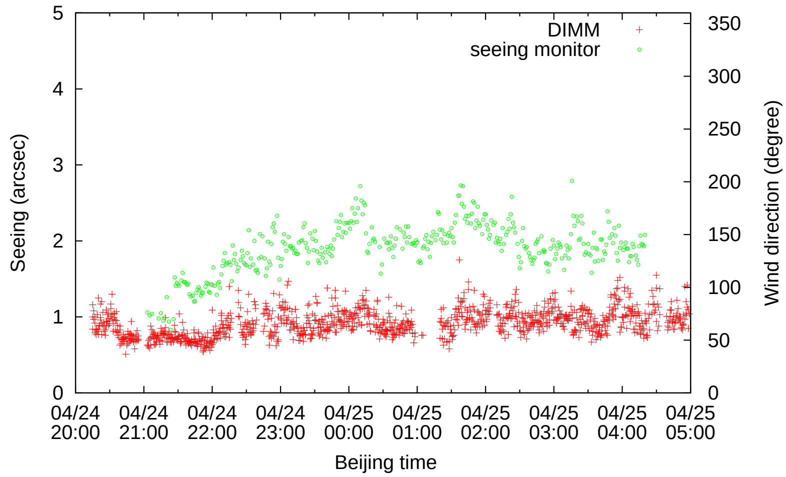

Fig. 6 Comparison of DIMM and Polaris seeing during the night of April 24.

Due to the bad weather condition, the experiments with both the DIMM and Polaris seeing monitors simultaneously observing Polaris did not obtain valid data in this run. Thus, the calibration for the Polaris seeing monitor was not successful. The calibration results obtained by setting the two instruments to simultaneously observe Polaris will be presented in another paper.

4.3 Wind Effect on the Polaris Seeing

Figure 7 shows the results of Polaris seeing and wind speed and direction by the weather station during the night of April 24. It can be seen that the seeing values, wind directions and wind speeds display correlations to some degree within different time intervals. From 21:00 to 23:00, the surface wind speed gradually increased, and the wind direction was 330–350 degrees, approximately in the direction of north, and the seeing values increased slightly with wind speed. However, the wind direction changed to the west (250–270 degrees) around 23:00; the seeing values appeared to be highly correlated with wind speed.

The Polaris seeing monitor is fixed on an equatorial mount along the north-south direction, therefore, the instrument has a larger capacity to resist wind load in the north-south direction than in the east-west direction. In the case of a wind gust from the east-west direction, the Polaris monitor should more easily get some trivial jittering. That could be the reason for the visual correlation between seeing values and wind speeds, when the wind direction turned to the west direction. Considering that the star trial method cannot eliminate instrument jittering, we should be very careful when using the SBIG Polaris seeing monitor. Besides implementing full reinforcement to resist the wind, whenever there is strong windy weather, it is absolutely necessary to perform a comprehensive analysis combining wind speed and direction.

4.4 Results of Seeing Measurements at Xinglong

In view of the seeing measurements resulting from several campaigns over the last 15 yr, Song et al. (1998) carried out four nightly measurements using DIMM in December, 1994, and obtained an average of the coherent length of 8 cm, corresponding to a seeing of 1.4″. The observations were run in the 2.16 m telescope dome, so the seeing values should be considered to be superimposed on the dome seeing. The 2.16 m optical telescope is an R-C system; its aperture for the main mirror

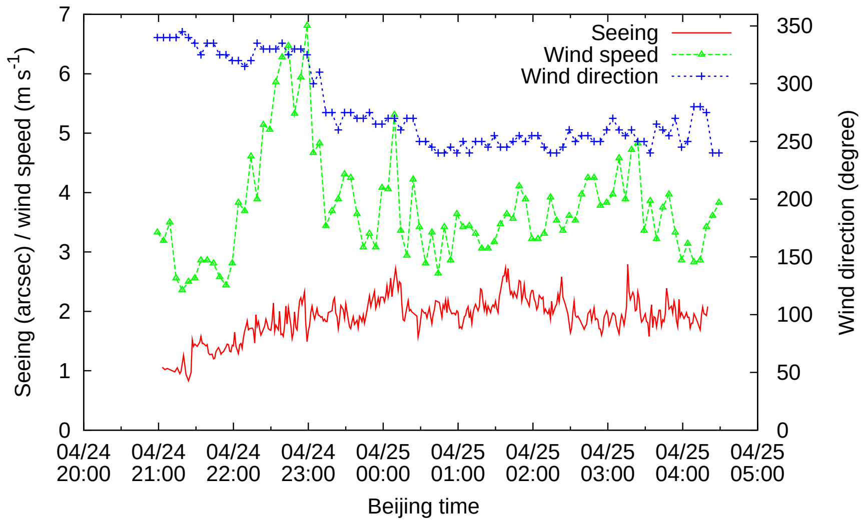

Fig. 7 Correlation analysis between Polaris seeing values and wind during the night of April 24.

is 2.16 m and the focal ratio of the Cassegrain focus is f/9. Liu et al. (2003) calculated statistics on the FWHMs of Polaris images from 1995 to 2001, and provided a seeing distribution of 90% FWHMs in 2″–5″. All the Polaris images are obtained by the BATC telescope, which is a large field multi-color sky survey project with a Schmidt telescope of aperture 60/90 cm and a combined ratio of f/3 (Liu et al. 2003). Therefore, it is also composed of the dome seeing. In addition, the FWHM method includes other non-atmospheric turbulence factors in the observing system, such as telescope tracking, optical imaging quality, and detector noise, so the result must be biased to a larger seeing. It is worth noting, however, that Liu et al. (2003)'s studies cover a very long term, and the result could be an important reference for the seeing condition at the Xinglong station, especially in understanding the seasonal variation of seeing conditions.

The full series of seeing measurements obtained at Xinglong observatory in different periods are summarized in Table 3. Song et al. (1998) presents the seeing measurements employing both the DIMM and FWHM methods, and the average FWHM seeing value (2.61″) is a double of the average DIMM seeing (1.32″), which further implies that the FWHM results by Liu et al. (2003) may greatly underestimate the seeing conditions at Xinglong observatory. Referring to the results by Song et al. (1998), most of the seeing values presented in Liu et al. (2003) should be below 2.0″. Based on the seeing measurements of several campaigns for the last 15 yr, the seeing at Xinglong observatory can be estimated to be 1″–2″. At present, since LAMOST has started recording observations, it is of great significance to perform long-term seeing monitoring at Xinglong observatory.

Table 3 Seeing Results of Xinglong Observatory at Different Periods

Period	Night	Height (m)	Spring (″)	Summer (″)	Autumn (″)	Winter (″)	Reference
1994 Dec.	4	15	–	–	–	1.4	Song et al. (1998)
1995–2001	All	6	3.4	2.9	3.7	3.9	Liu et al. (2003)
2003 Oct.	3	15	–	–	–	1.3	Zenno et al. (2004)
2007 Mar.	12	28	1.1	–	–	–	This work

5 CONCLUSIONS

The seeing measurements were carried out with DIMM at the LAMOST observatory at the Xinglong site in 2007 March to April. The main results in this study may be summarized as follows:

(1) The median seeing over the 12 nights is measured to be 1.1″, and the mean seeing is 1.2″. Among the total 9259 data sets, 25% of the seeing values are better than 0.8″, and 75% are better than 1.5″.
(2) The experiment on DIMM exposure time shows that exposure time may have a significant impact on seeing measurements. There is a good correlation among seeing values with different exposure times, and scaling factors for correcting to a standard exposure time which could be obtained by linear regression. For detecting the real seeing condition, a DIMM exposure time should be taken to be less than 10 ms.
(3) The Polaris seeing monitor can provide a rather good seeing trend comparable with the DIMM measurements. However, the Polaris seeing is clearly affected by wind gusts, leading to larger seeing values. Therefore, besides the full reinforcement, the Polaris seeing monitor needs a critical correction by combining it with simultaneous meteorological and DIMM monitoring.
(4) Based on the seeing measurements of several campaigns for the last 15 yr, we estimate the annual seeing condition at Xinglong observatory to be about 1″–2″.

Acknowledgements This work was supported by the National Natural Science Foundation of China (Grant Nos. 10903014 and10778709), and by the Young Researcher Grant of National Astronomical Observatories, Chinese Academy of Sciences.

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